

SUMMARY OF RESEARCH
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**WAKE MANAGEMENT STRATEGIES FOR REDUCTION OF
TURBOMACHINERY FAN NOISE**

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The primary objective of our work was to evaluate and test several wake management schemes for the reduction of turbomachinery fan noise. Throughout the course of this work we relied on several tools. These include 1) Two-dimensional steady boundary-layer and wake analyses using MISES (a thin-shear layer Navier-Stokes code), 2) Two-dimensional unsteady wake-stator interaction simulations using UNSFLO, 3) Three-dimensional, steady Navier-Stokes rotor simulations using NEWT, 4) Internal blade passage design using quasi-one-dimensional passage flow models developed at MIT, 5) Acoustic modeling using LINSUB, 6) Acoustic modeling using VO72, 7) Experiments in a low-speed cascade wind-tunnel, and 8) ADP fan rig tests in the MIT Blowdown Compressor. The principal results of our research efforts are summarized below. More detailed discussion of the results (along with descriptions of the analytical, numerical and experimental tools) can be found in Waitz et al., "Preliminary Assessment of Wake Management Strategies for Reduction of Turbomachinery Fan Noise," (*J. Propulsion and Power*, v12, No4, 1996), Brookfield, Waitz and Sell, "Rotor Wake Decay: Effect of Swirl," (*J. Propulsion and Power*, v14, No2, 1998), and Brookfield and Waitz, "Trailing Edge Blowing for Reduction of Turbomachinery Fan Noise," (AIAA Paper 98-2321, 4th AIAA/CAES Aeroacoustics Conference, 1998).

Summary of Research Results:

1. Trailing edge blowing is in general a more attractive strategy than blade boundary layer suction for minimizing the wakes shed from high bypass ratio fans. Successful application of boundary layer removal requires that treatment be applied to both sides of the blade, which is difficult structurally. Further, for typical blade thicknesses, choking of the flow internal to the blade as it is accelerated inwards (due to the centrifugal pressure gradient) limits the mass flow to somewhat less than would be required for full boundary layer removal. Also the suction pressure can be no lower than vacuum at the hub so there is a limited pressure drop to drive the flow. For trailing edge blowing, the flow accelerates as it moves outward in the blades, and a relatively small overpressure (e.g. 0.15 times the fan total pressure) is required to provide enough mass flow to fill the wake. Flow at this pressure is readily available within the first few stages of the low compressor. For trailing edge blowing, filling of the wake can be achieved using less than 2% of the fan throughflow. Results of a quasi-one-dimensional passage flow model which show these general trends are given in Figure 1.
2. Cascade testing was performed on several different suction and trailing edge blowing geometries. These tests showed that trailing edge blowing from discrete slots is most effective for reducing the spatial harmonics of the wake. Further, the flow should be injected from the suction surface of the airfoil at a small angle which accounts for the deviation of the flow near the trailing edge and thus results in blowing into the center of the wake. Indeed, for situations which produced a momentumless wake ($\theta=0$), very substantial reductions of the wake harmonic amplitudes were obtained as shown in Table 1.

**Table 1: Estimated Acoustic Mode Amplitude Reductions at $x/c = 1.5$
for Experimental Cascade Trailing Edge Blowing**

Mode	Δ Mode Amplitudes (dB)		
	-25% \dot{m}	$\theta = 0$	+25% \dot{m}
2 x BPF, $m = -8$	-8.0	-24.4	-3.9
3 x BPF, $m = 8, -32$	-8.1	-18.6	-2.6
4 x BPF, $m = 24, -16, -56$	-8.3	-13.2	+0.8
Broadband Noise	-6.6	-7.0	-0.9

3. Rig testing was carried out on a 1/6th-scale Pratt and Whitney ADP fan stage with blades incorporating internal passages for trailing edge blowing. A schematic of one of the blades is shown in Figure 2, a photograph of the rotor is shown in Figure 3. Two different spanwise blowing distributions were tested; for each, the mass flow injected from the trailing edge was less than 2% of the fan throughflow. Time-mean and turbulent profiles of the rotor-relative Mach number were obtained, along with stator unsteady loading measurements. As shown in Figure 4, significant filling of the time-mean wake profile was achieved with reductions in the first three BPF harmonic amplitudes of up to 85% at 1.5 chords downstream of the rotor. In addition, stator measurements showed reductions in the stator unsteady loading of up to 10 dB. The results demonstrate that trailing edge blowing is effective for reducing the rotor wakes and their mean harmonic amplitudes. Further, significant control of the radial phase variation of the wake harmonic amplitudes was demonstrated through overblowing the wake in various regions.
4. The rig testing results also demonstrated that with injection, considerable reduction of the rotor-stator spacing may be possible with no increase in the radiated acoustics relative to the baseline configuration. Wake relative Mach number BPF and 2*BPF harmonic amplitudes at 0.1 chord with injection were near or below the amplitudes at 1.5 chord without injection.

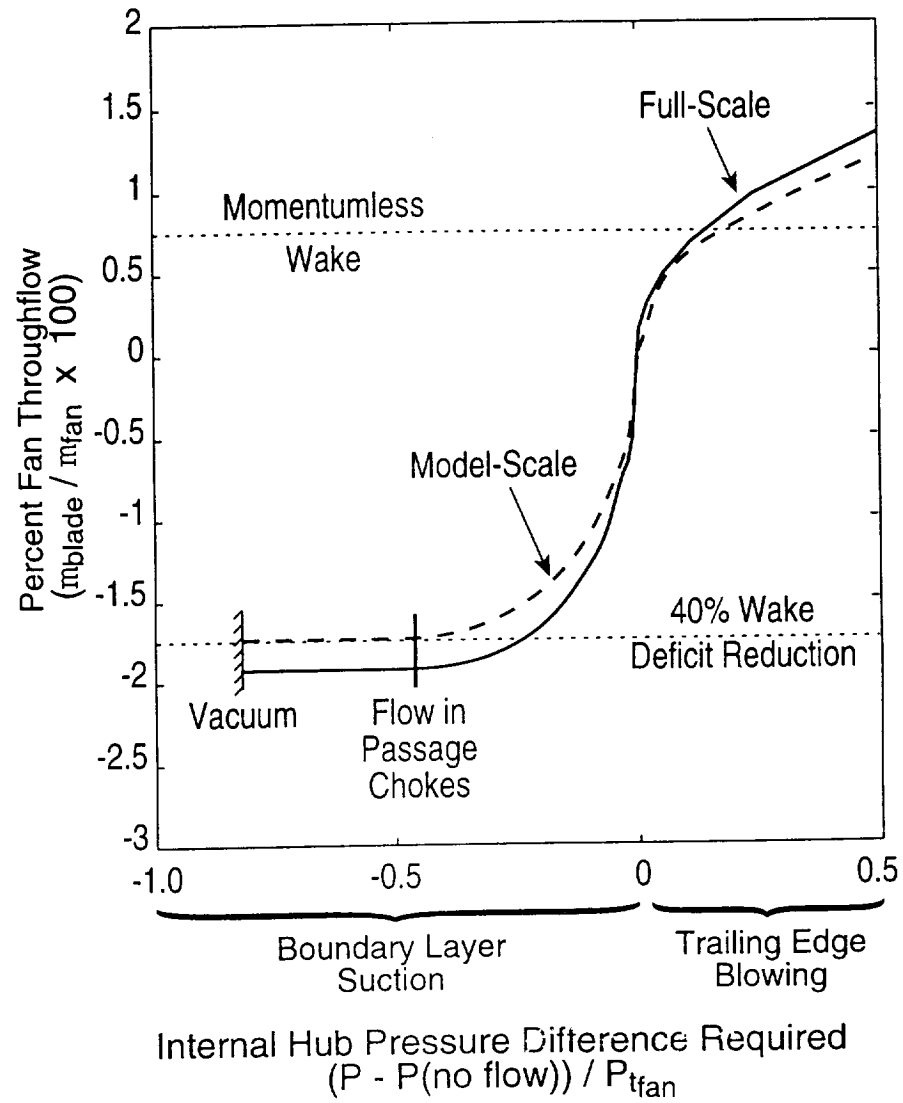


Figure 1. Suction and blowing performance for a sample blade design.

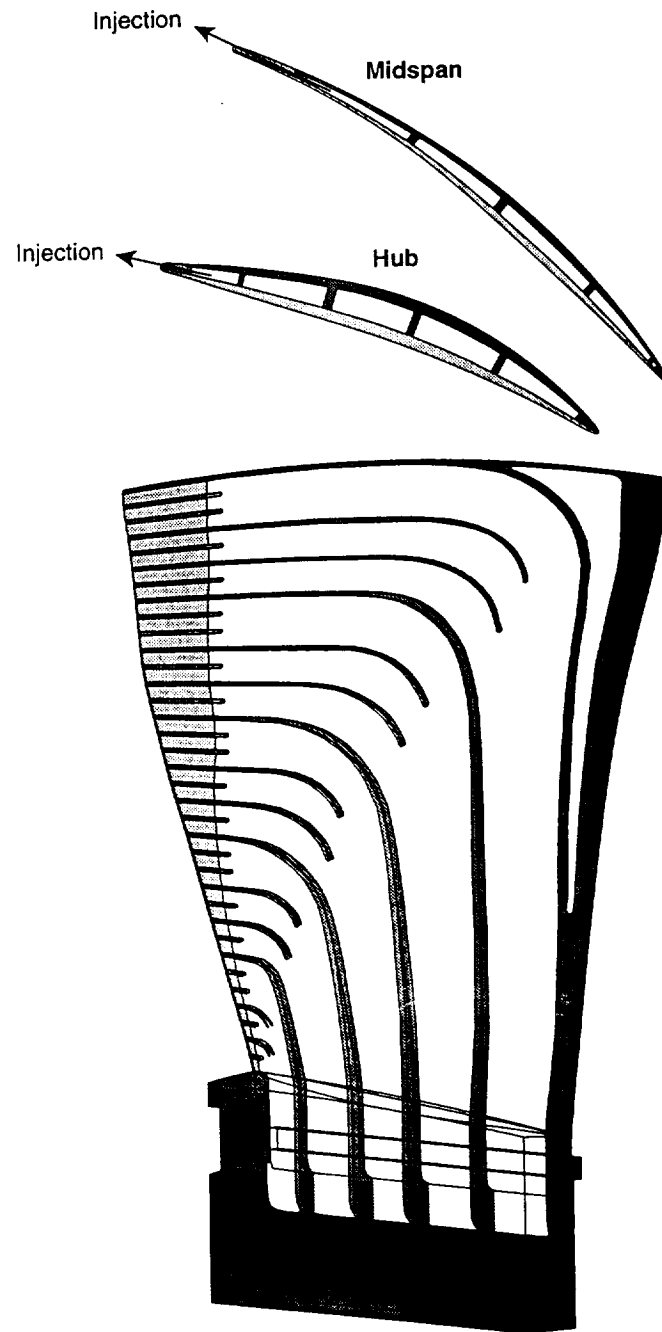
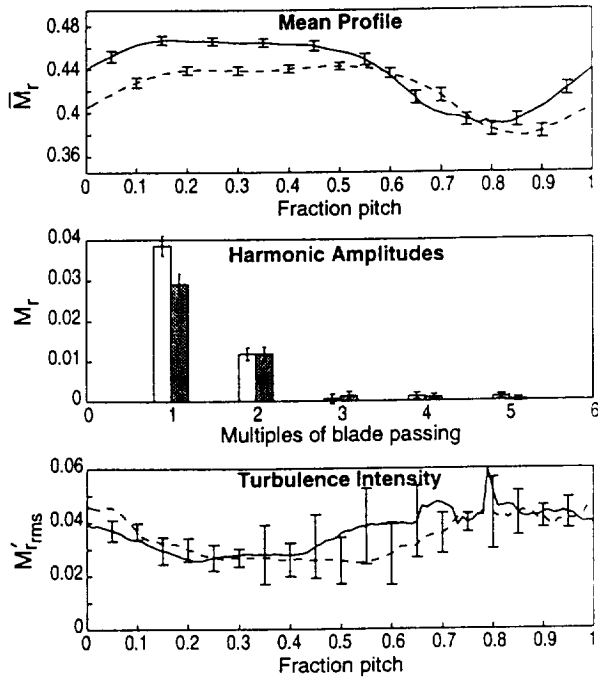


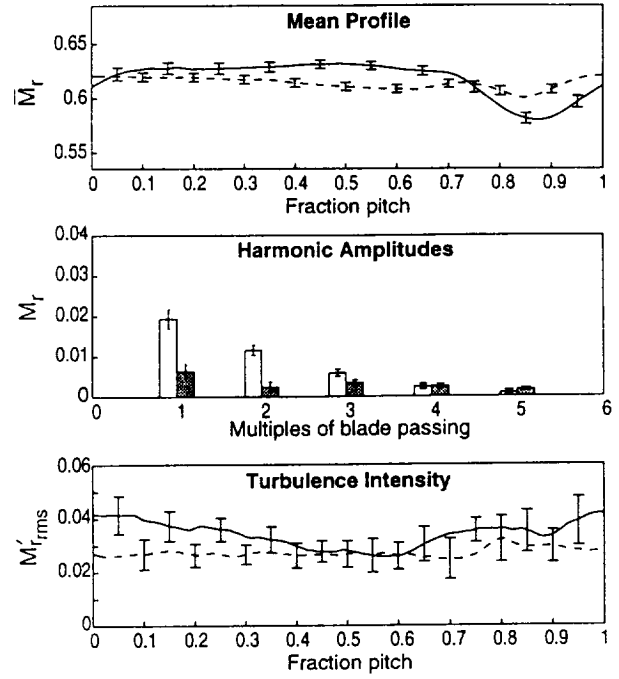
Fig. 2: Schematic of trailing edge blowing fan blade: perspective view and hub and midspan cross-sections.



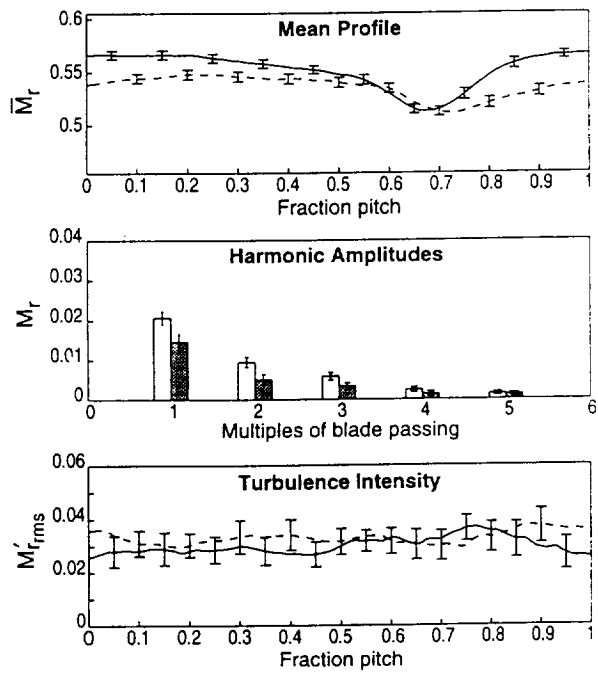
Fig. 3: Trailing edge blowing rotor.



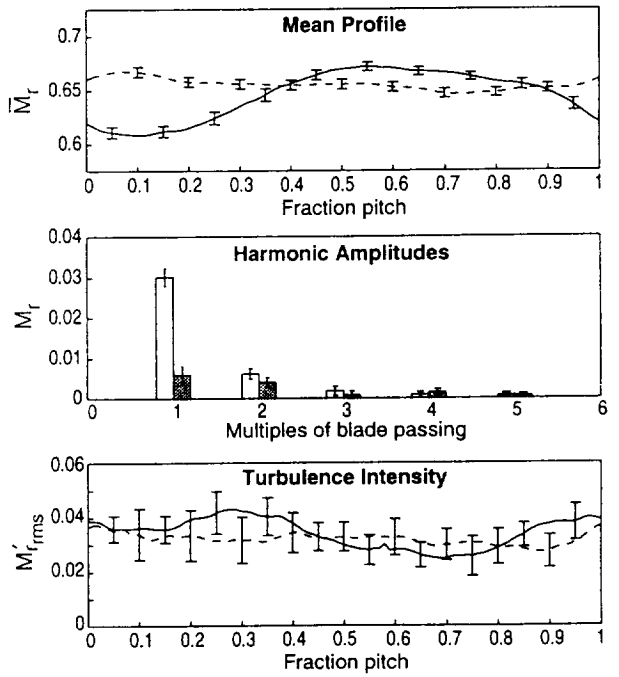
(a) 25% Span



(c) 75% Span



(b) 50% Span



(d) 87.5% Span

Fig. 4: Wake behavior with and without blowing at 1.5 chords downstream of the rotor trailing edge for tip-weighted injection. The solid curves correspond to no injection and the dashed curves (and shaded bars) correspond to injection of 1.9% of the fan throughflow.